How Pervasive is "Fishing Down Marine Food Webs"?

In their report (*1*), and in an earlier paper (*2*), D. Pauly *et al*. draw global conclusions about the effects of fishing on world fish stocks with the use of research data fitted to Ecopath models at different sites through the world's oceans, integrated with data on global fishery landings collected by the Food and Agricultural Organization of the United Nations (FAO). Although Pauly *et al*. are to be congratulated for giving this important issue high profile, they greatly oversimplify the situation with their hypothesis and may have misinterpreted the FAO statistics. We do not disagree that a general decline in mean trophic level of marine landings is likely to have occurred in many regions, but we are not convinced that the explanation is solely a result of "fishing down the food web" or that the analysis of the FAO data, as undertaken by Pauly *et al*., substantiates such a thesis.

Four considerations significantly qualify the evidence of a "fishing down the food web" phenomenon.

(i) Taxonomic resolution. Assigning a trophic level arguably requires knowing at least the related genus or even the species and its age, since trophic level may change by as much as three points from birth to maturity for some top predators. Although the FAO fishery landings data (*3*) used in their analysis integrate the best estimates by countries, regional fishery organizations, and FAO of the species composition of annual production, it is to be regretted that over 30% of all marine landings cannot be identified to the species level, and about 20% cannot even be assigned to the level of Family (this rises to about 60% for inland capture fishery production). As a consequence, the small drop in mean trophic level they report, from 3.3 in the early 1950s to 3.1 in 1994, appears difficult to substantiate statistically, and its sensitivity to the assumptions necessarily made in allocating coarse data to trophic levels has not been described.

(ii) Landing data as ecosystem indicators. The analysis assumes that changes in mean trophic level in the landings reflect changes in the ecosystem, with the use of annual quantities of landings (excluding discarded catch) as abundance indicators. However, the composition of historical landings has been affected by a number of phenomena that are not simply related to increased fishing pressure (for example, natural oscillations in abundance, changes in fishing technology) and that are likely to have seriously influenced mean trophic levels in the landings.

Overfishing has seriously affected top predators, and this has already been raised in FAO reports (*4*). Peaks in predatory demersal fish production and subsequent declines have been registered that differ in timing regionally and among different habitat types (*5, 6, 7*). Comparing regional landings of demersal fish (generally, long-lived species high in the food chain) with short-lived species such as squid (*8*) also reveals trophodynamic effects quite clearly. There seem to be few other hypotheses to account for declines in landings of top predators than overfishing.

The situation is not the same for species lower in the food chain, where natural medium-term fluctuations of the small pelagic species abundance are likely to quantitatively mask effects that result from declining top predators on the mean trophic level. In addition, long-term changes in strategies of fishing such species add to the difficulty of documenting global trends through a "mean trophic level" for the ecosystem as a whole. This task requires detailed knowledge of local fisheries in order to extrapolate safely from "trophic level of landings" to "trophic level of ecosystems."

Outside the north boreal area, and except for a few very large oscillating stocks (for example, Peruvian anchoveta), small pelagics were rarely subjected to major exploitation in the 1960s and 1970s because of lower market prices and because technologies for handling and processing the catch were not yet fully developed. During the last two decades, these species have seen a significant increase in their exploitation resulting from the spread of new technologies. One could argue that this increase is indeed due to increase abundance of pelagics resulting from depletion of their predators, but this remains conjecture. The fact is that the interest of industries for small pelagic fish increased, leading to higher landings of these species and shifts in the composition of global landings. A shift in global fishing strategies could be confused with a "fishing down the food web phenomenon."

(iii) Aquaculture development. FAO landing statistics have traditionally included both capture and aquaculture production, but work is under way to disaggregate them into the two separate components. This has so far been completed for years since 1984. As a rough check, mean trophic levels for species groups as reported in (*2*) were applied to marine landings of the corresponding species groups to calculate the overall mean trophic level of total production (capture fishery plus aquaculture production) since 1950 and capture fisheries and aquaculture since 1984. In contrast to the decline in mean trophic level reported by Pauly *et al*., for marine waters the mean trophic level for capture fishery landings has remained stable since 1984 (Fig. 1) at a level similar to that of total production in the early decades when marine aquaculture was insignificant. The decline in mean trophic level in the total production series is entirely a result of the increasing contribution of aquaculture to total production (from 8% in 1984 to 17% in 1996) and the fact that species cultured in the sea (mainly shellfish) have an average trophic level about half that of capture fishery landings (Fig. 1). That the results of Pauly *et al*. (*1*) for all marine waters

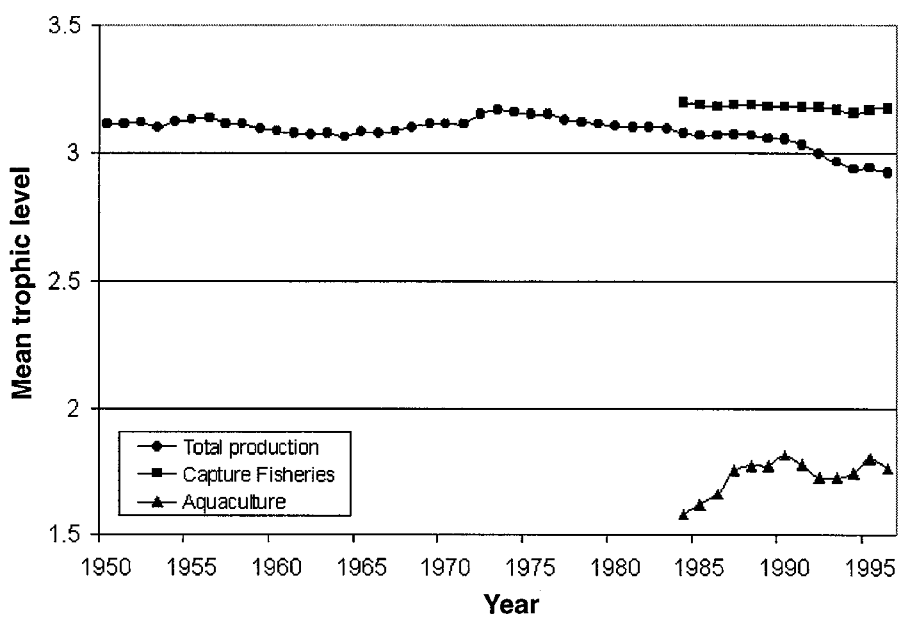

Fig. 1. Trends in mean trophic level of landings from marine waters.

more closely resemble the trend of total production rather than that of capture fishery landings in Fig. 1 suggests that aquaculture production may not have been fully excluded from their analysis.

Capture fishery data for inland waters are lacking in taxonomic definition: about 60% are not even assigned to the Family level, and so trophic analysis is not possible. Even if there is a decline in the mean trophic level for inland capture fisheries, it need not necessarily reflect "fishing down the food chain," because there are complications such as large-scale stock-enhancement practices (for example, stocking to the wild, fertilizing reservoirs) as well as pollution that will affect species composition.

(iv) Eutrophication of coastal areas. Accumulating evidence from coastal and semi-enclosed seas suggests that land-based runoff, by increased primary productivity along coastlines, may have exerted a "bottom up" effect in increasing abundance of planktivores, thus lowering mean trophic level. This effect is most easily documented where anthropogenic eutrophication has occurred. In the Black Sea, hypoxic effects have decimated demersal species, again decreasing mean trophic level without necessarily implying "fishing down the food web." Similar examples may be cited from the Baltic (*9*), Black Sea (*10*), Mediterranean (*11*), and Seto Inland Sea (*12*). Hypoxia has even been recently documented as a serious problem in open-sea areas such as the Gulf of Mexico (*13*). As a diffuse and general phenomenon, eutrophication is a strong potential source of modification of the ratio between demersal and pelagic fish and between predator and prey abundances that could also be confused with "fishing down the food web."

All these points imply that, even if the mean trophic level of landings was higher earlier on (which in our view is not proven), this does not necessarily reflect "fishing down the food web," because overall landings have increased substantially in recent decades, contrary to what was stated in the report (*1*).

We concur with Pauly *et al*. that the mean trophic level for most marine fish species rises with age, which adds another level of uncertainty to their analysis. For example, a bluefin tuna may rise by three trophic levels or more during its life history, as may other large predators that are planktivorous in the larval and post larval stages. This variation makes assigning a single trophic level to a species, which is the practice in Ecopath models, a hazardous procedure. As noted by Pauly *et al*., the model may actually have underestimated the decline in mean trophic level as the mean age and trophic level of a species has declined with increasing fishing intensity.

We do not mean to imply that "fishing down the food chain" is not a major cause of changes to fish communities worldwide, but the situation of marine fisheries is complex (*14*), and shows wide regional variation. Oversimplifying a key issue like this could inhibit local research on human impacts on marine food chains that should not be confined to impacts of the fishing industry. Local analyses of food webs using methods promoted by Pauly *et al*. should be combined with local knowledge of fisheries and research data that take into account possible causal hypotheses. Identification of specific effects of human activities could then lead to locally appropriate management solutions.

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Response: Our report (*1*) received a lot of media attention, some of it overenthusiastic. Thus, we are pleased that Caddy and his colleagues at FAO have provided, through their detailed comment, an opportunity to elaborate on the process of fishing down marine food webs, wherein fishing fleets actively and increasingly target species low in the food web. Caddy *et al.* seem to agree with us when they state that "a general decline in mean trophic level of marine landings is likely to have occurred in many regions." They question, however, whether FAO landing data can be used to demonstrate the existence of this trend.

We would like to clear up two possible misunderstandings before we turn to the four objections made by Caddy *et al.* First, we did not state, or imply, that low trophic level species increased their contribution to global catches because of a "depletion of their predators." Rather, we suggested that continuation of the trend to fish down marine food webs must eventually lead to declines of overall catches (both predator and prey species), resulting in "backward-bending" curves of trophic level against these catches [figure 5 in (*1*)]. We identified several mechanisms that could generate such curves, including one in which the removal of top predators reduces the production of their prey. This mechanism is different from the "predator depletion" model.

Second, values produced by the mass-balance ("Ecopath") ecosystem models, from which we extracted the more than 200 estimates of trophic level used to compute mean trophic levels of FAO landings, were not values that were "assigned," that is, input into Ecopath, but values that were estimated by Ecopath, on the basis of observed diet compositions. We now turn to the four considerations raised by Caddy *et al.*

(i) The lack of "taxonomic resolution" is indeed a problem in the FAO landing data set. However, we demonstrated global and broad regional trends toward lower trophic level in spite of about half of the world's landings being assigned to excessively broad categories, such as "mixed fishes." This is especially true in tropical developing countries, and as fishing down marine food webs also occurs in these countries (Fig. 1A), the overall effect is actually much stronger than we were originally able to show. FishBase 98 (*2*) may be used to generate graphs similar to that for Cuba in Fig. 1A for a vast array of countries, all with similar trends, even where overaggregated regional data do not exhibit fishing down marine food webs. As a rule, we find that the better the taxonomic resolution, the stronger the effect of fishing down marine food webs appears.

(ii) Using "landing data as ecosystem indicators" is not really a problem: landings of major resource species should generally reflect the relative magnitudes of their biomasses in the ecosystems from which the landings are extracted. Thus, Peruvian landings consist mainly of anchoveta because these are abundant in the Peruvian upwelling ecosystem, and Indonesian coastal fishers land ponyfishes because these are abundant on the Sunda Shelf. Off Newfoundland, Canada, where cod was targeted until it recently collapsed, a fishery for invertebrates has recently developed. It can be safely expected that Newfoundland's future landing statistics will reflect the species shift that occurred in the ecosystem around that island.

Such correspondence between relative abundance in the landing and in the ecosystems was not the rule before fisheries became globalized, and only selected species were exploited by nearshore gear. Now, with inshore, offshore- and distant-water fleets competing to supply increasingly integrated global markets, abundant species are exploited wherever they occur (*3*), and landings will tend to reflect their relative abundance. Moreover, there is evidence for fishing down marine food webs in fisheries, independent of FAO data (*4*). One example is the nearly two decades of well-documented surveys in the Gulf of Thailand (*5*, figure 1A). There, fishing down marine food webs cannot be shown when using highly aggregated, regional FAO data (*1*). Also, given the strong positive relationship, in aquatic ecosystems, between trophic level and size (*6*), both within and between species (Fig. 2), the occurrence of fishing down marine food webs implies a reduction of mean size for the exploited components of aquatic ecosystems. Reduction of mean sizes in multispecies fisheries catches (commercial and surveys) are themselves very well documented in the literature (*7*).

Caddy *et al.* state that we did not consider within-species (that is, ontogenic) changes of trophic level. (We admit having planned to leave this for another paper.) In fish, trophic level does not simply "change" during the transition from larvae to adults: it increases (Fig. 2B). Because most species of fish, globally, "have seen a significant increase in their exploitation resulting from the spread of new technologies," their mean size, and thus their mean trophic level, cannot but have declined in recent years. Our not considering, in the report, within-species changes of trophic level masked the full extent of fishing down marine food webs, instead of artificially creating it, as implied by Caddy *et al.*

(iii) Aquaculture development is another issue we had reserved for a later contribution. The trend of trophic level in global aquaculture is the opposite of that in fishing down marine food webs: it is increasingly carnivorous, high-trophic-level species (salmon, groupers) that are cultivated, while the low-trophic-level (herbivorous and detritivorous) species popular in developing countries (tilapia, carp) are either phased out or grown for sale to upscale markets, using fish meal or other high-protein diets. Similarly, the transition from wild-caught (largely detritivorous) penaeid shrimps to shrimp culture, relying on

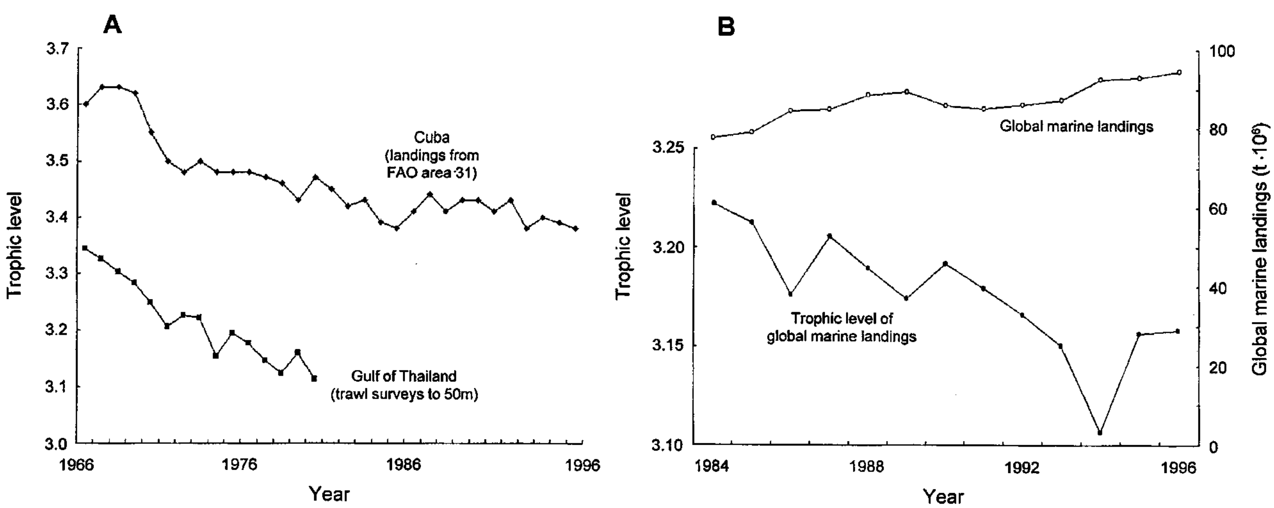

Fig. 1. Trophic level trends (**A**) in Cuban landings from the Western Central Atlantic (FAO area 31, 1966 to 1996) and in Gulf of Thailand trawl survey data, 1966 to 1982 (*4*); (**B**) in global marine fisheries, 1984 to 1996 (from FAO landings, also shown), after removal of mariculture production data.

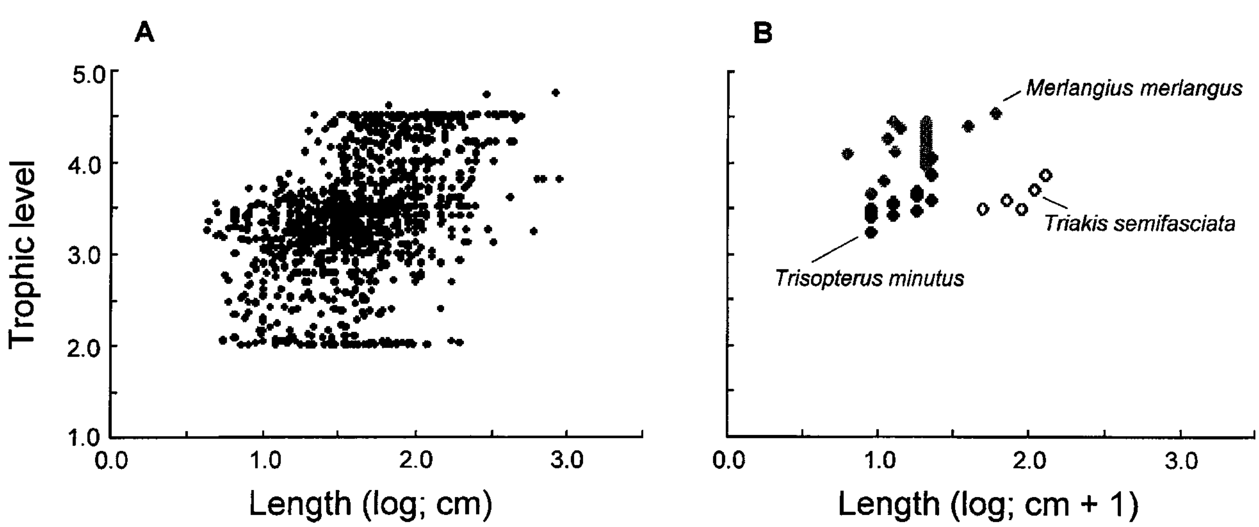

Fig. 2. Relationships between trophic level and body length in fish. (**A**) Trophic level from diet compositions versus maximum length in 1143 species. (**B**) Trophic level from diet compositions versus mean predator length in three representative species. All data are from FishBase 98 (*2*).

high-protein pelleted feeds, also implies a trophic-level increase.

Caddy *et al.* attempt to demonstrate (figure 1 in their comment) (*8*) that the inclusion of aquaculture production in FAO landing data may have produced, rather than masked, the decline of trophic level we reported. We re-analyzed the FAO database, after excluding freshwater fishes, non-fish vertebrates such as whales, and algae and other plants—as we had done before—and also excluding aquaculture production from 1984 on (to reflect when the FAO Aquaculture Production database started). The result shows the same decline as reported earlier, about 0.1 trophic level unit per decade (*1*). Indeed, a decline of trophic level also occurs in figure 1 of the comment by Caddy *et al.*, even for their 1984–1996 series, presenting landings minus aquaculture production, although this trend is barely visible, due to the inappropriate scale of that figure (*8*).

(iv) Eutrophication of coastal areas may have caused a "'bottom up' effect in increasing abundance of planktivores, thus lowering mean trophic levels." We agree that this effect may be one of the causes for some of the observed declines in the trophic level of fisheries landings—if we assume that, indeed, changes in abundance in the ecosystem tend to be reflected in the landings. This, however, is a point Caddy *et al*. did not grant us in other parts of their comment.

Currently, eutrophication is limited to coastal areas, including parts of the Mediterranean. In the Black Sea and along the Louisiana Coast (Gulf of Mexico), the existing fisheries have become shadows of their former selves because of overfishing, extreme eutrophication, and other anthropogenic disturbances. This is likely also to have happened in other areas similarly affected, but on the global level, catches from such areas are not significant, and thus will have only minor impact on trends of trophic level.

Caddy and his colleagues have documented, and tried to halt, the excessive global fishing capacity that has depleted major fisheries (*3*). We, and they, have relied on the vast effort that went into generating and maintaining the global FAO database of landings and related data. We have supported this effort and shown in our report how combining the contents of this database with the knowledge derived from ecosystem models can provide further insight into what is happening globally.

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6. We take this opportunity to (i) correct a slip of the pen in our report (*1,* p. 862), in which we wrote of an "inverse" relationship between trophic level and length: the two are positively correlated; and (ii) point out that trophic-level estimates based on diet composition data analyzed with Ecopath correlate closely with trophic-level estimates based on stable isotope ratios, notwithstanding size effects [T. C. Kline Jr. and D. Pauly, in *Alaska Sea Grant College Program Report No. 98-01.* (University of Alaska Fairbanks, Fairbanks, AK, in press); see also www.ecopath.org].
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8. Figure 1 in the comment by Caddy *et al*. has several problems. It is based on 39 highly aggregated trophic level estimates from an earlier contribution of D. Pauly and V. Christensen [*Nature* **374**, 255 (1995)], rather than on the more than 200 estimates of trophic level we used for our report (*1*) and made available through www.fishbase.org. Further, it suggests trophic level values for aquaculture as a whole to be increasing from 1.55 in 1984 to about 1.7 to 1.8 in the 1990s. Such low trophic levels require that mariculture production of plants (trophic level = 1) be high relative to that of herbivores/detritivores (trophic level = 2), and carnivores such as salmon (trophic level $\gg$ 2, because their diet includes animal products, such as fish meal). Last, we do not see what algae and seagrasses, explicitly excluded from the computations in our report (*1*), can contribute to a debate about fishing down marine food webs, except to generate an inappropriate ordinate scale for graphs of trophic level over time [see E. R. Tufte, *The Visual Display of Quantitative Information* (Graphic Press, Cheshire, CT, 1983)].

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